Technology Outreach

John Mester

GP-B Technology Outreach

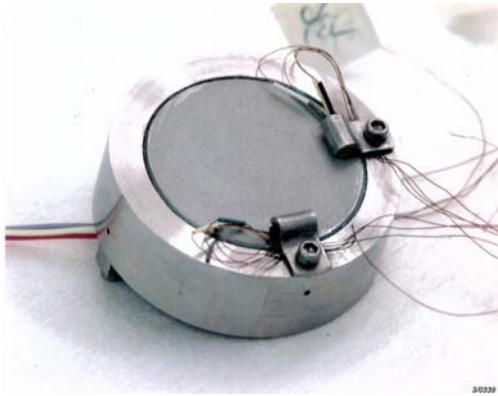
- **Task Group on GP-B, Space Studies Board NRC, 1995**
  - **Concluding Observation: Technology Transfer**
    - » **"The task group strongly urges that the technology developed during NASA's support of GP-B be reported soon in the open literature for the benefit of the entire scientific community"**

- **Task Group's charge is as yet only partially fulfilled**

Successful Technology Transfer

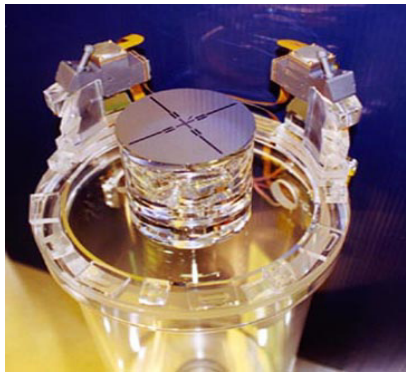
Porous Plug Device - HeII Phase Separation In Space

Selzer, Fairbank, and Everitt, Adv. Cryo. Eng., 16:277 (1971)
Developed for GP-B, flown on COBE, IRAS, Spitzer(SIRTF)



Hydroxide catalyzed bonding - Optobond™

Licensed by Schott and other optics cos
Applied in Ground-based, (LIGO &GEO 600)
and SPACE based gravitational wave Detectors, (LISA)



Real-time Kinematic GPS - Novariant Inc,

Spacecraft Attitude Determination
AutoFarm, mining, automated landing

Post Launch Technology Publications 1

- **Spacecraft and Payload**

  Gravity Probe B Post Flight Analysis – Final report (2007). http://einstein.stanford.edu/content/final_report/GPB_FinalPFAR-091907-scrn.pdf,

  Precision electrostatic suspension system for the Gravity Probe B relativity mission's science gyroscopes Bencze, M.E. Eglington, R.W. Brumley and S. Buchman Advances in Space Research Volume 39, Issue 2, 2007, Pages 224-229

  Super NiCd Energy Storage for Gravity Probe-B Jeffrey Hayden, Bob French., Gary Mason and Shawky Shehata 3rd International Energy Conversion Engineering Conference San Francisco, California AIAA 2005-5599, 2005

- **Telescope System**

  Initial Evaluation of the GP-B Cryogenic Telescope Performance in Orbit, Wang, S; Farley, R. P.; Goebel, J. H.; Keiser, G. M.; Lipa, J. A.; Turneaure, J. P. LT24. AIP Conference Proceedings, Volume 850, pp. 1621-1622 (2006).

  Performance of the GP-B cryogenic guide-star telescope detectors, Goebel, J; Farley, R; Keiser, G.; Kirschenbaum, J, Turneaure, J.; Wang, S. Infrared and Photoelectronic Imagers and Detector Devices. Proc. of the SPIE, Volume 5881, pp. 261-265 (2005).

Post Launch Technology Publications 2

- **Space Cryogenics**

  Flight Performance of Gravity Probe B Cryogenic System. D. O. Murray. M. A. Taber Advances in Cyrogenic Engineering: 1303 (12) 2006

- **GPS Applications**

  Gravity Probe B GPS Receivers, P. Shestople, J. Li, A. Ndili and K. Schrock, Proceedings of the 17th International Technical Meeting of the Satellite Division of the Institute of Navigation ION GNSS 2004

  Attitude Determination of the Gravity Probe B Spacecraft Using GPS Receivers P. Shestople, J. Li, A. Ndili, A. Parchuri and N. Vora, Proceedings of the 18th International Technical Meeting of the Satellite Division, Institute of Navigation ION GNSS 2005

  Time Transfer Between UTC and Local Vehicle Time for the Gravity Probe B Relativity Jie Li, George M. Keiser, James M. Lockhart and Paul Shestople, Proceedings of the 60th nnual Meeting ION GNSS Institute of Navigation, p. 560 – 570 2004

  Gravity Probe B GPS Orbit Determination with Verification by Satellite Laser Ranging G. Hanuschak, H. Small, D. DeBra, K. Galal, A. Ndili and P. Shestople
  Proceedings of the 18th International Technical Meeting of the Satellite Division of the Institute of Navigation ION GNSS 2005

Post Launch Technology Publications 3

- **Attitude and Translation Control**

On-Orbit Performance of the Gravity Probe B Drag-Free Translation Control System Bencze, W.J., DeBra, D.B., Herman, L., et al. Proc. 29th Guidance and Control Conference. American Astronautical Society, Breckenridge, Colorado, (2006).

On-Orbit Performance of Gravity Probe B Drag-Free Translation Control and Orbit Determination, J. Li, W.J. Bencze, D.B. DeBra, G. Hanuschak, T. Holmes, G.M. Keiser, J. Mester, P. Shestople and H. Small ; *Advances in Space Research*, *Volume **40**, Issue 1 pp 1-10* (2007)

Generic Drag Free Control Simulaiton: Lessons Leaned from Gravity Probe B, I. Pelivan, S. Smoot, D. Hipkins and Stephan Theil, AAS 08-011, 31st Annual AAS Guidance and Control Conference, Breckenridge, Colorado, Febuary (2008)

Proportional Helium Thrusters for Gravity Probe B (AAS 08-038) D. B. DeBra, W. J. Bencze, C. W. F. Everitt, J. VandenBeukel and J. Kirschenbaum Volume 131 Advances In The Astronautical Sciences, Proceedings of the 31st Annual AAS Rocky Mountain Guidance and Control Conference 2008

Post Launch Technology Publications 4

- **APS 2007 April Meeting Posters** http://einstein.stanford.edu/highlights/hl_041407.html#poster

* L1.00012: "Radio Imaging of the Gravity Probe B Guide Star IM Pegasi" Michael Bietenholz, Ryan Ransom, Norbert Bartel, Daniel Lebach, Michael Ratner, Irwin Shapiro, Jean-Francois Lestrade
* L1.00013: "The 'Core' of the Quasar 3C454.3 as the Extragalactic Reference for the Proper Motion of the Gravity Probe B Guide Star" Norbert Bartel, Ryan Ransom, Michael Bietenholz, Jerusha Lederman, Daniel Lebach, Michael Ratner, Irwin Shapiro, Leonid Petrov
* L1.00014: "Performance of the Gravity Probe B Inertial Reference Telescope" by Suwen Wang, John Goebel, John Lipa John Turneaure
* L1.00015: "Gravity Probe B Timing System and Roll Phase Determination" by Jie Li , Jeffery Kolodziejczak
* L1.00016: "The Gravity Probe B SQUID Readout Detector" by Barry Muhlfelder, Bruce Clarke, Gregory Gutt, James Lockhart, Ming Luo
* L1.00017: "SQUID Control, Temperature Regulation, and Signal Processing Electronics for Gravity Probe B" by James Lockhart, Barry Muhlfelder, Jie Li, Bruce Clarke, Terry McGinnis, Peter Boretsky, Gregory Gutt
* L1.00018: "Gravity Probe B Science Instrument Assembly (SIA)" by Saps Buchman, Barry Muhlfelder, John Turneaure
* L1.00019: "Polhode Motion of the Gravity Probe-B Gyroscopes" by M. Dolphin, A. Silbergleit, M. Salomon, P. Worden, D.DeBra
* L1.00020: "Evidence for Patch Effect Forces on the Gravity Probe B Gyroscopes" by D. Gill, S. Buchman
* L1.00021: "Gravity Probe B Orbit Determination" by Paul Shestople , Huntington Small
* L1.00022: "Simulator Technology of the Gravity Probe-B Mission" by D. Hipkins , R. Brumley , Y. Ohshima , T. Holmes
* L1.00023: "Achievement of the Magnetic Environment Requirements for Gravity Probe B" by J. Mester, J. Lockhart, M.l Taber
* L1.00024: "The Gravity Probe B Gyroscopes" by S.s Buchman, B. Clarke, Mac Keiser, P.Zhou, D. Gill, F. Marcelja, R. Brumley
* L1.00025: "Gravity Probe B Gyroscope Electrostatic Suspension System (GSS)" W. Bencze, Hipkins, Holmes, Buchman, Brumley
* L1.00026: "The Gravity Probe B Relativity Mission (GP-B)" by C.W. Francis Everitt
* L1.00027: "Gravity Probe B Experiment Error" by Barry Muhlfelder, G. Mac Keiser, John Turneaure
* L1.00028: "Gravity Probe B Science Data Analysis: Filtering Strategy" by M. Heifetz, T. Holmes, D. Hipkins, A. Silbergleit, V. Solomonik
* L1.00029: "Performance of the Gravity Probe B Cryogenic Sub-System" by Michael Taber, David Murray
* L1.00030: "The Gravity Probe B Drag-free and Attitude Control System" by Michael Adams, Daniel DeBra
* L1.00031: "Features of the Gravity Probe B Space Vehicle" by William Reeve, Gaylord Green
* L1.00032: "Classical Torques on Gravity Probe B Gyroscopes" by Alex Silbergleit, G. Mac Keiser, Yoshimi Ohshima
* L1.00033: "Trapped Flux Mapping for the Gravity Probe B Gyroscopes" M Salomon,J Conklin, M Dolphin, G Keiser, A Silbergleit,P Worden

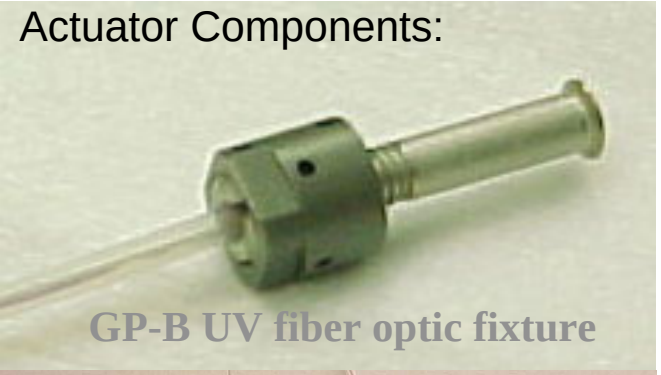
Work in Progress

- Key Technologies of GP-B Impact Future Missions
- Important to examine both technologies that worked as designed and those that had issues
- Areas undergoing studies
  - Charge Control
  - Patch Effect
  - Precision Attitude and Drag Free Control

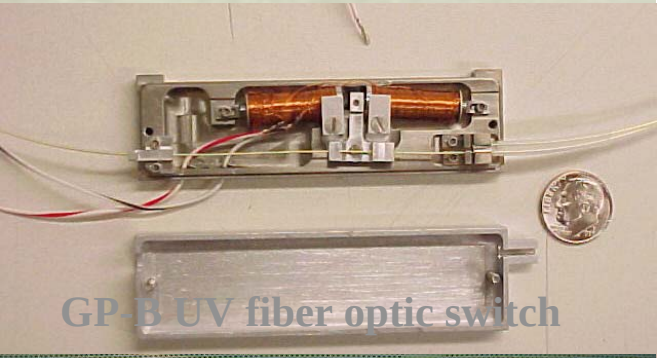
UV Charge Control

- Rotor charge controlled via UV excited electrons
- Charge rates ~ 0.1 mV/day
- Continuous measurement at the 0.1 mV level
- Control requirement: 15 mV

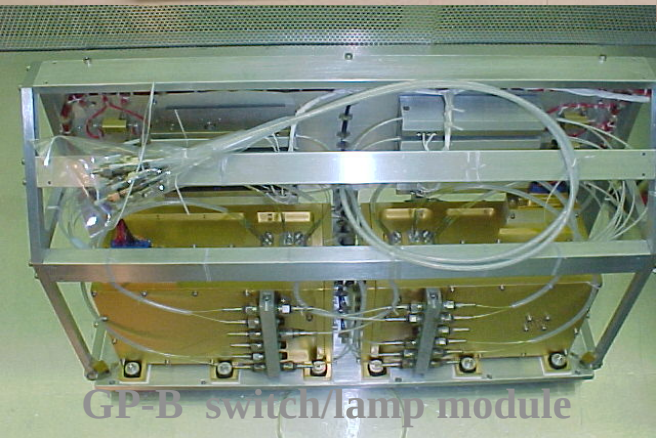
Actuator Components:



GP-B UV fiber optic fixture

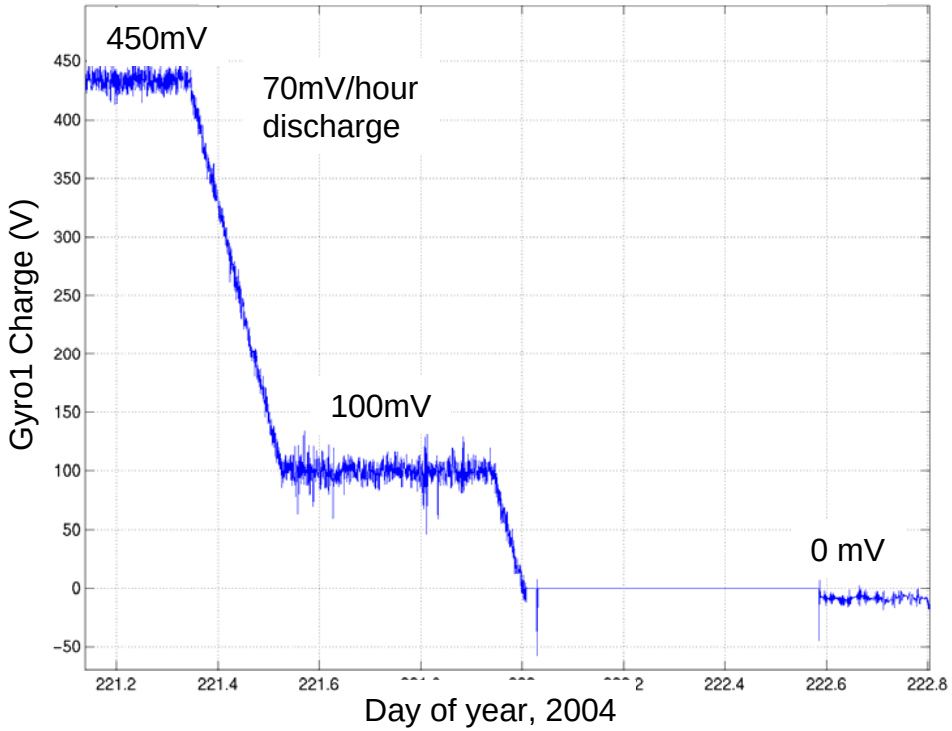


GP-B UV fiber optic switch



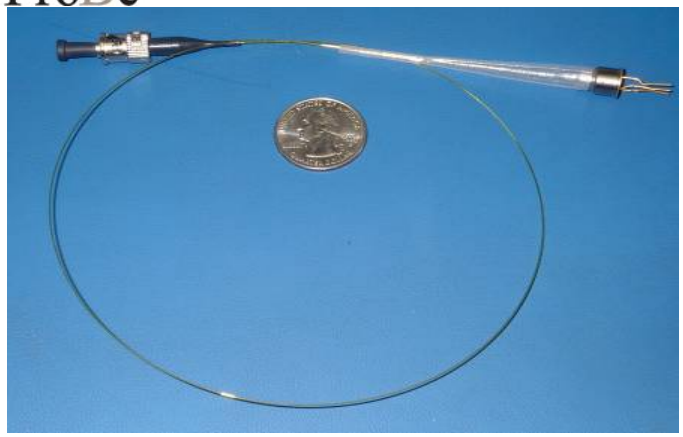
GP-B switch/lamp module

Discharge of GP-B Gyro1



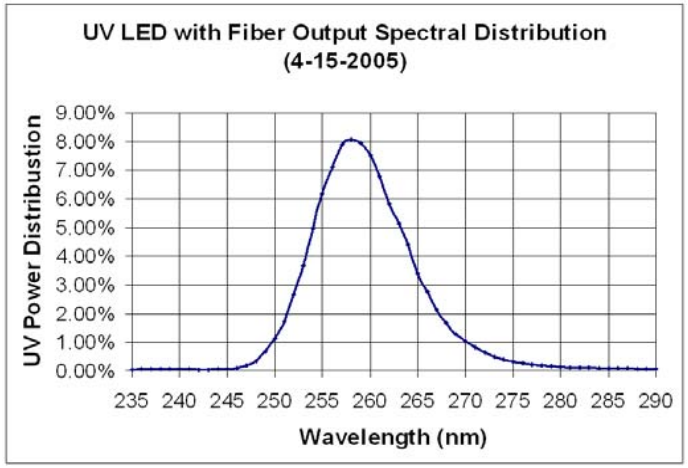
Worked as designed: Charge controlled to < 5 mV

LED Deep UV Source for Charge Management



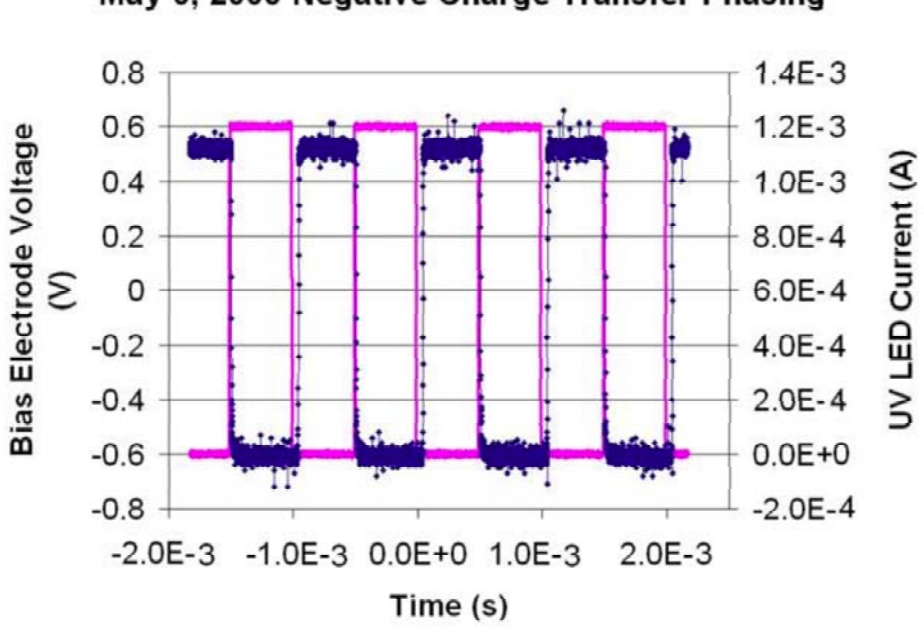
UV LED System Developed By SU LISA Team

- Light weight
- Low electrical power
- Compact, robust
- Fast modulation => enables novel operation



Total UV power 0.144 mW

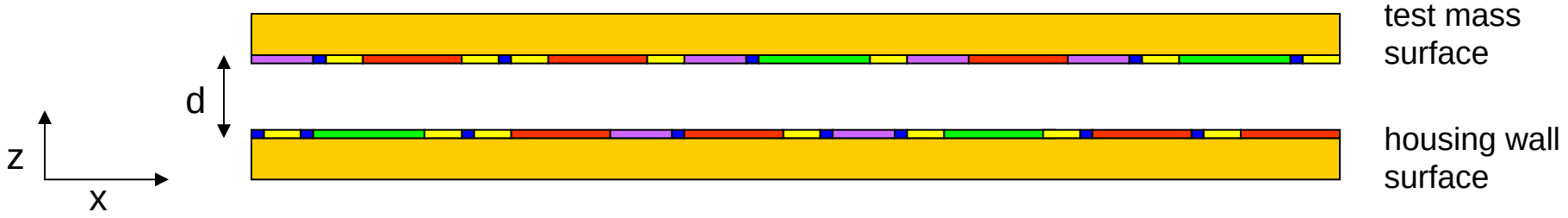
UV LED & Bias modulated at 1kHz



K. Sun, B. Allard, S. Williams, S. Buchman, and R. L. Byer, "LED Deep UV Source for Charge Management for Gravitational Reference Sensors," *Class. Quantum Grav.* 23 (2006) S141-S150

The Patch Effect

- Spatial variations in surface potential root cause of GP-B Issues
  - Polhode damping, misalignment torques, resonance torques



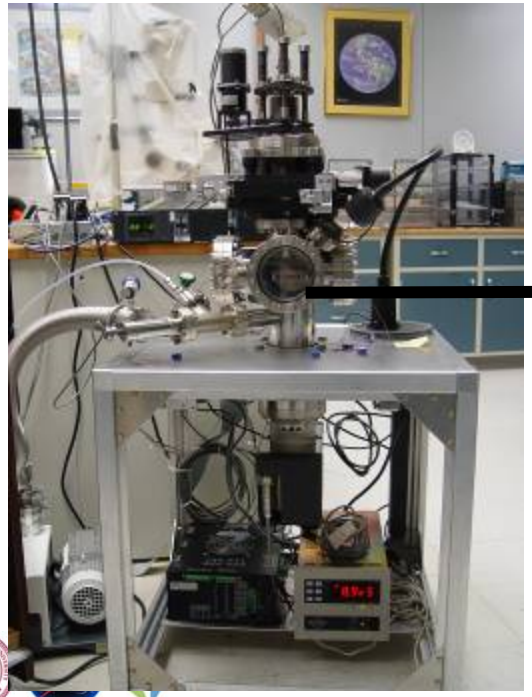
- Paper detailing GP-B patch analysis and evaluating trades for future Missions is undergoing internal review
  - Lead Author Sasha Buchman

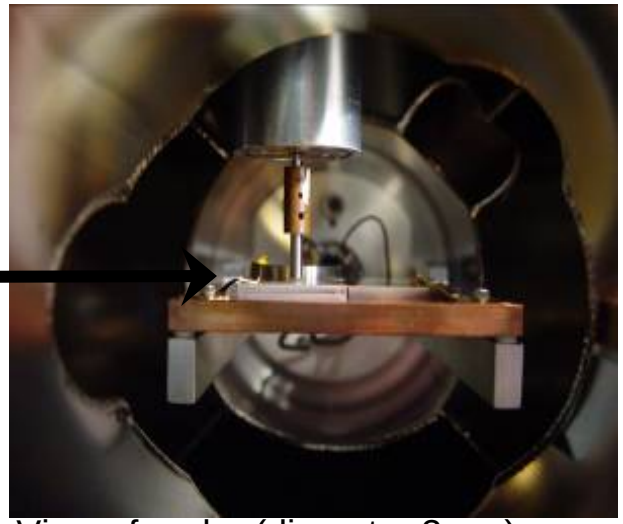
- Analytic Model of Electrostatic Interaction of STEP Test Masses

  (Valerio Ferroni & Alex Silbergleit)
  - Patch Effect–Drag Free Performance Connection

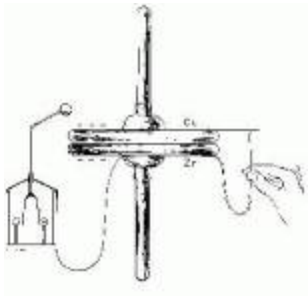
Kelvin Probe Patch Measurements

- In addition to flight data analysis ground measurements program initiated
- Kelvin Probe measures contact potential between a conducting specimen and a vibrating probe tip
  - non-contact, non-destructive vibrating capacitor device





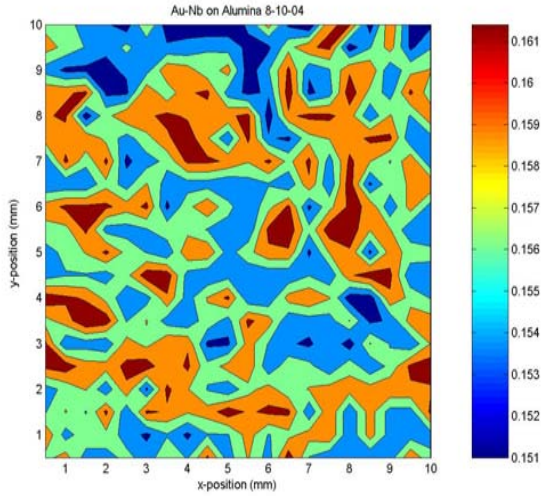
View of probe (diameter 3mm) sitting above samples



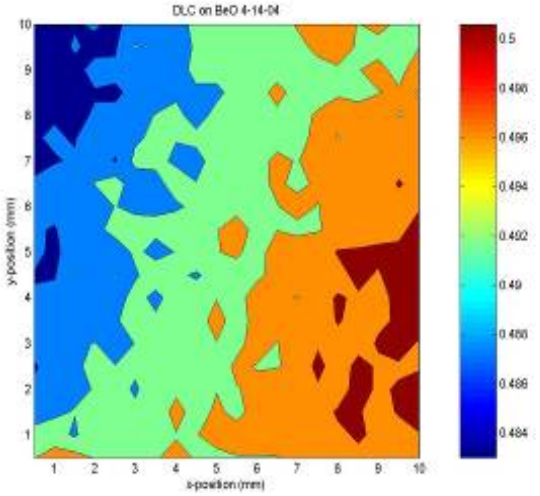
Kelvin's original apparatus

Examples of Spatial Scans

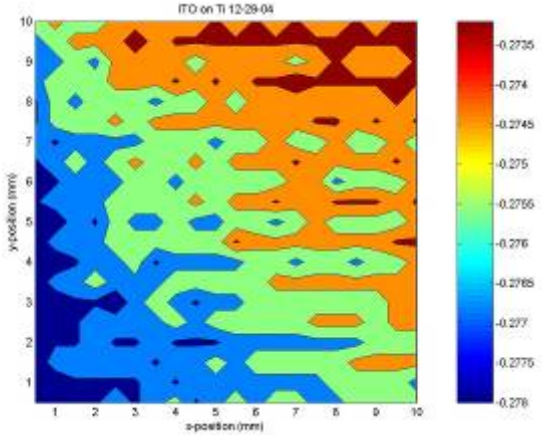
Gold-niobium on alumina (p-to-p 13 mV)



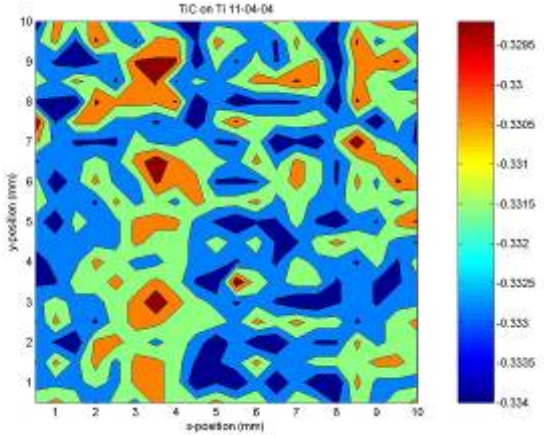
Diamond-like carbon on beryllia (p-to-p 22 mV)



Indium tin oxide on titanium (p-to-p 6 mV)

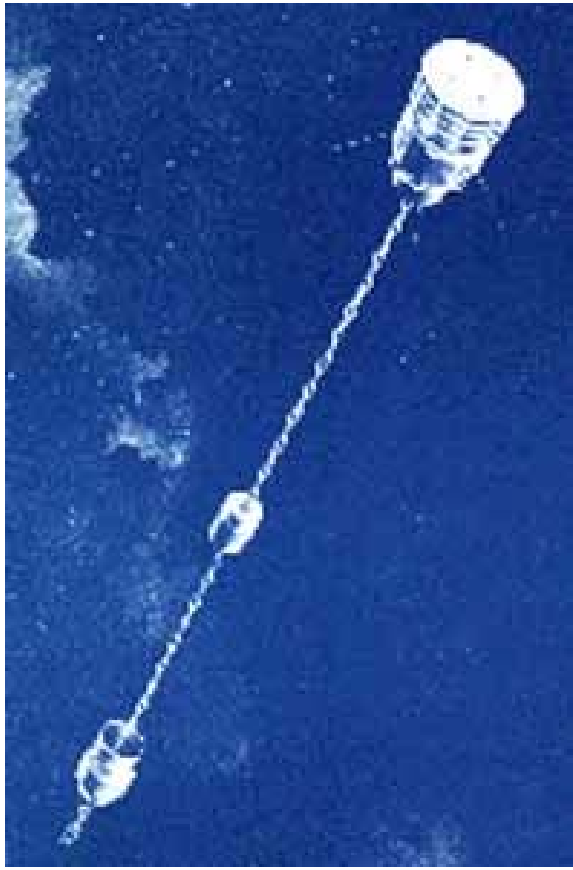


Titanium carbide on titanium (p-to-p 6 mV)



Contact potential difference in volts over 10 mm by 10 mm area (400 data points).

Drag Free Control



Drag-Free Satellite History

- TRIAD I : DISCOS - Disturbance Compensation System
  - 3 axis translation control PI, Dan DeBra, Stanford,
  Navy Transit Navigation Program, JHU APL
  Launched September 2, 1972, Polar Orbit at 750 km

- TIPs & NOVA One axis translation control
  Transit Program 1975-1984 JHU APL & RCA
  Paul Worden, Stanford Consultant

- And Now Also GP-B
  3 axis translation control
  3 axis active attitude control

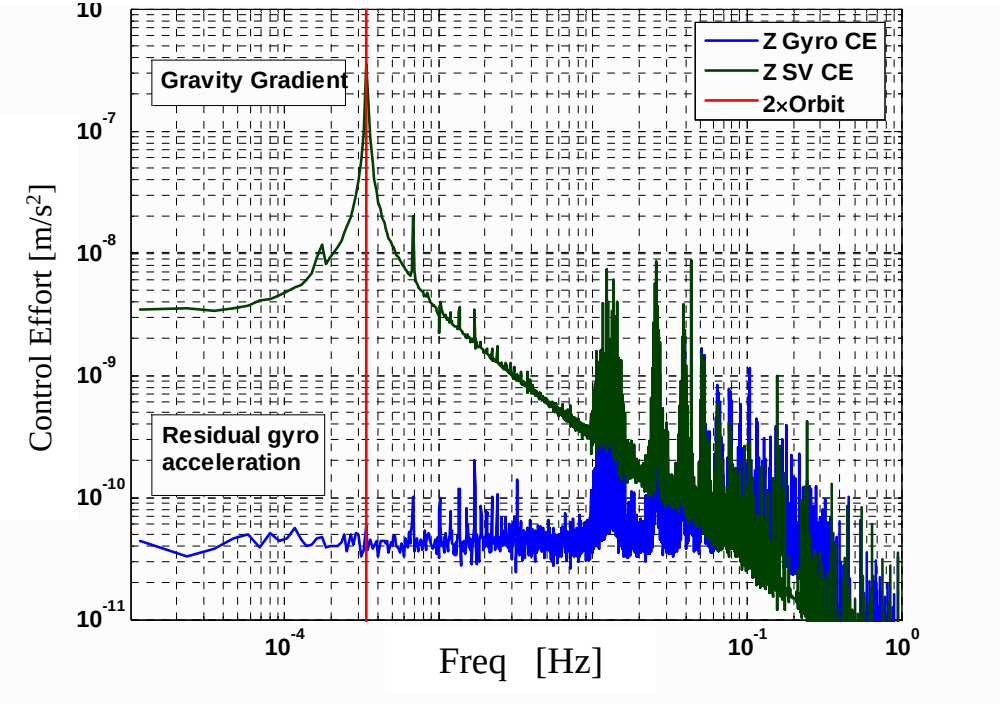
Drag Free Control Lessons Learned

Initial Orbit Checkout (IOC), successful but challenging

4 month duration, 2 months planned

>10,000 commands sent

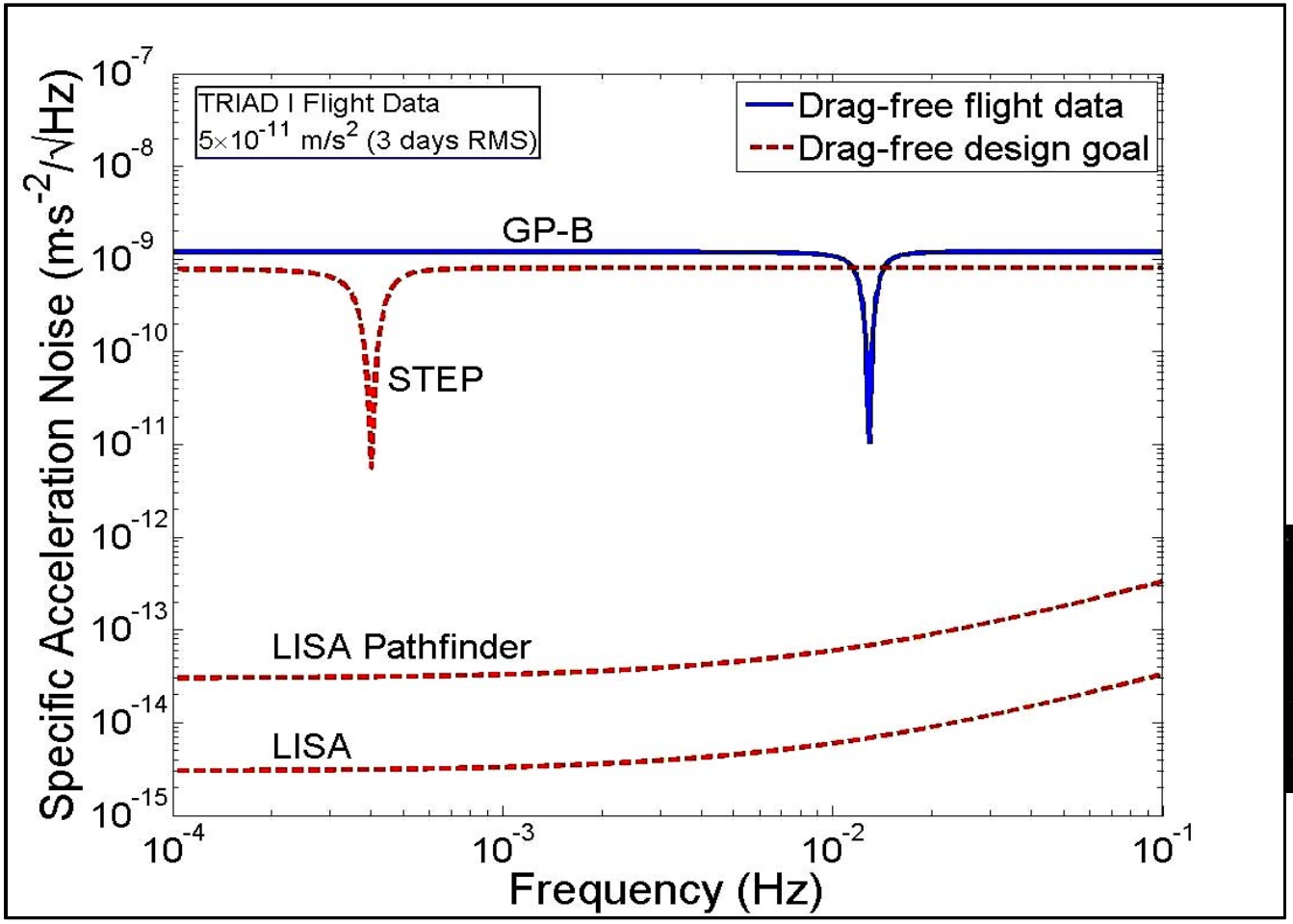
Performance Requirements Ultimately Achieved

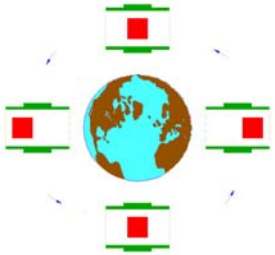


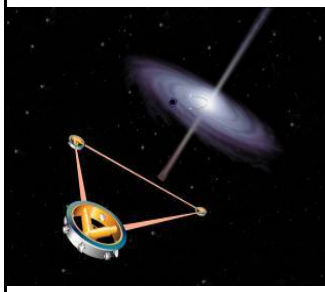
High fidelity integrated payload/spacecraft simulator is valuable on orbit.

Advantage in use of simulators early in mission development life cycle.

Future Mission Drag Free Control Requirements







- Requirements more stringent than GP-B
- Communication Challenges for non-LEO missions impact in-flight tuning
- More complex inertial sensors, multiple, non-spherical

Ongoing Attitude and Translation Control Work

- Analysis of ATC Engineering Data
  - ATC Simulator Development for Future Missions
  - Use GP-B data to validate simulator
  - Inertial Sensor Modelling

- Collaborating Institutions
  - ZARM ‘First Look’ Program
    - » ZARM, University of Bremen, Matthias Matt, Ivanka Pelivan, Stefan Theil
    - » Institute of Astronomy, Cambridge University, GAIA group
  - University of Rome ”la Sapienza”, Valerio Ferroni
  - KACST, Badr Alsuwaidan

ATC Future Work

- Develop fully integrated sensor-controller-actuator simulations operating across the payload/spacecraft interface
- Exploit modular architecture to enable exchange of software models for hardware units for hardware-in-the-loop verification
- Use high fidelity spacecraft bus and flight CPU to enable flight software validation and verification with the science payload
- Integrate Mission Operations consoles for command generation and verification - anticipate in-flight tuning

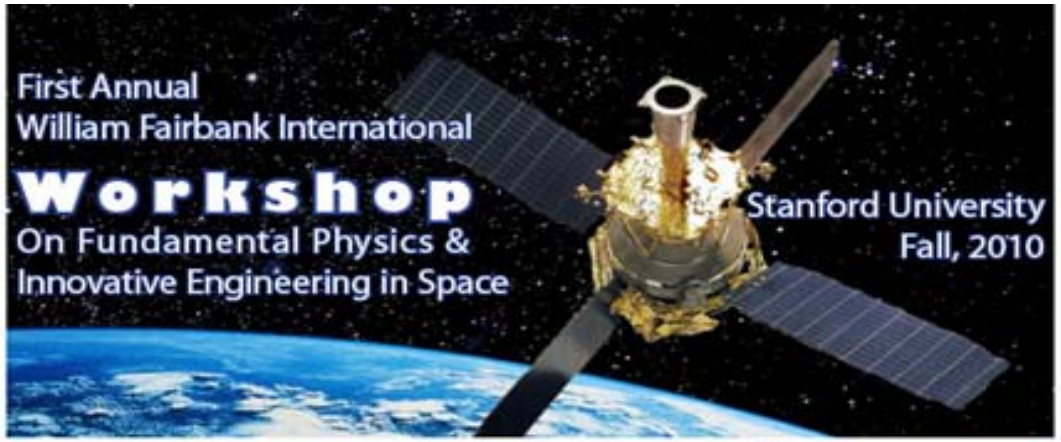
GP-B Technology: AA255 Course

- Stanford Aero/Astro Department Sponsoring 3 Unit Course on Space Systems
  - Gravity Probe B to be Used as a Case Study

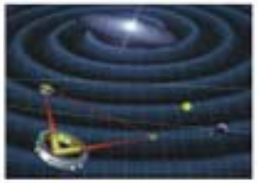
AA255 - Space Systems Engineering and Design

Systemized approaches to design, fabrication, integration, and testing of flight hardware from the component level through functional systems. The development of systems level requirements based on flow-down from mission requirements and goals. Comparison of systems engineering techniques related to requirements development, tracking, validation, and verification. An examination of risk tracking and mitigation. The development of the Gravity Probe B Relativity Mission will be used as a case study to illustrate key principles.

William Fairbank International Workshop



The marriage of applied physics and aerospace engineering, enabling fundamental physics experiments to be performed in space.



The space environment, combined with a wide range of new sensor and control technologies, opens many exciting opportunities for revolutionary, cutting-edge experiments in fundamental physics. Developing and deploying these new technologies places unprecedented demands for innovative engineering across multiple disciplines.

Who Should Attend?

- Experimental physicists, aerospace engineers, industrial leaders, university and governmental managers and policy makers.

Dedicated workshop sessions will include:

- **Proposed missions.** Physical foundations, core technical requirements, technology needs.
- **Mission design.** Instruments, space vehicles, operations. University-Industry-Government collaboration. Mission-specific reviews.
- **Technologies.** Breakthrough technologies, sensors, techniques, materials.
- **Project management and operations.** Simulation, testing/verification, operations tools, training, risk management, requirements specification and control.
- **Lessons Learned.** Instrument design and operation, data analysis, system-level interactions, modeling, environment.

Web Site: http://einstein.stanford.edu/fb_workshop
Email: fb_workshop@relgyro.stanford.edu

This conference is named in honor of William Fairbank. In an extremely productive career, Professor Fairbank demonstrated a powerful ability to bring physicists and engineers into creative exchange. His pioneering efforts were essential to many of the first generation of *fundamental physics in space* experiments. These missions include Gravity Probe A, Gravity Probe B, Lambda Point, CHeX and AMS. All were innovations, not only in technology, but in management and engineering approaches.